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De Dea et al.

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(54) **LIGHT COLLECTOR MIRROR CLEANING**

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(75) Inventors: **Silvia De Dea**, San Diego, CA (US);
Michael Varga, Fallbrook, CA (US);
Alexander I. Ershov, Escondido, CA
(US); **Robert L. Morse**, Vista, CA (US)

(73) Assignee: **ASML Netherlands B.V.** (NL)

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G02B 27/00 (2006.01)
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B23K 26/16 (2006.01)

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(2013.01); **B08B 11/02** (2013.01); **G02B**
27/0006 (2013.01); **B23K 26/0643** (2013.01);
B23K 26/16 (2013.01)

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USPC 134/28, 61, 92
See application file for complete search history.

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Primary Examiner — Michael Kornakov

Assistant Examiner — Natasha Campbell

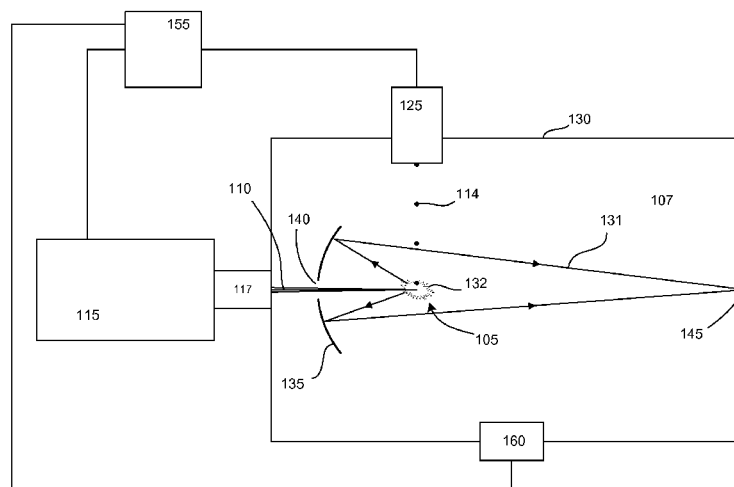
(74) *Attorney, Agent, or Firm* — DiBerardino McGovern IP
Group LLC

(57) **ABSTRACT**

A collector mirror of an extreme ultraviolet light source is
cleaned by removing the collector mirror from a chamber of
the extreme ultraviolet light source; mounting the collector
mirror to a carrier; inserting the carrier with the collector
mirror into a cleaning tank; applying a cleaning agent to a
reflective surface of the collector mirror by spraying the
cleaning agent through a plurality of nozzles directed toward
the collector mirror reflective surface until the collector mir-
ror reflective surface is clean; rinsing the applied cleaning
agent from the collector mirror reflective surface; and drying
the collector mirror reflective surface.

29 Claims, 13 Drawing Sheets

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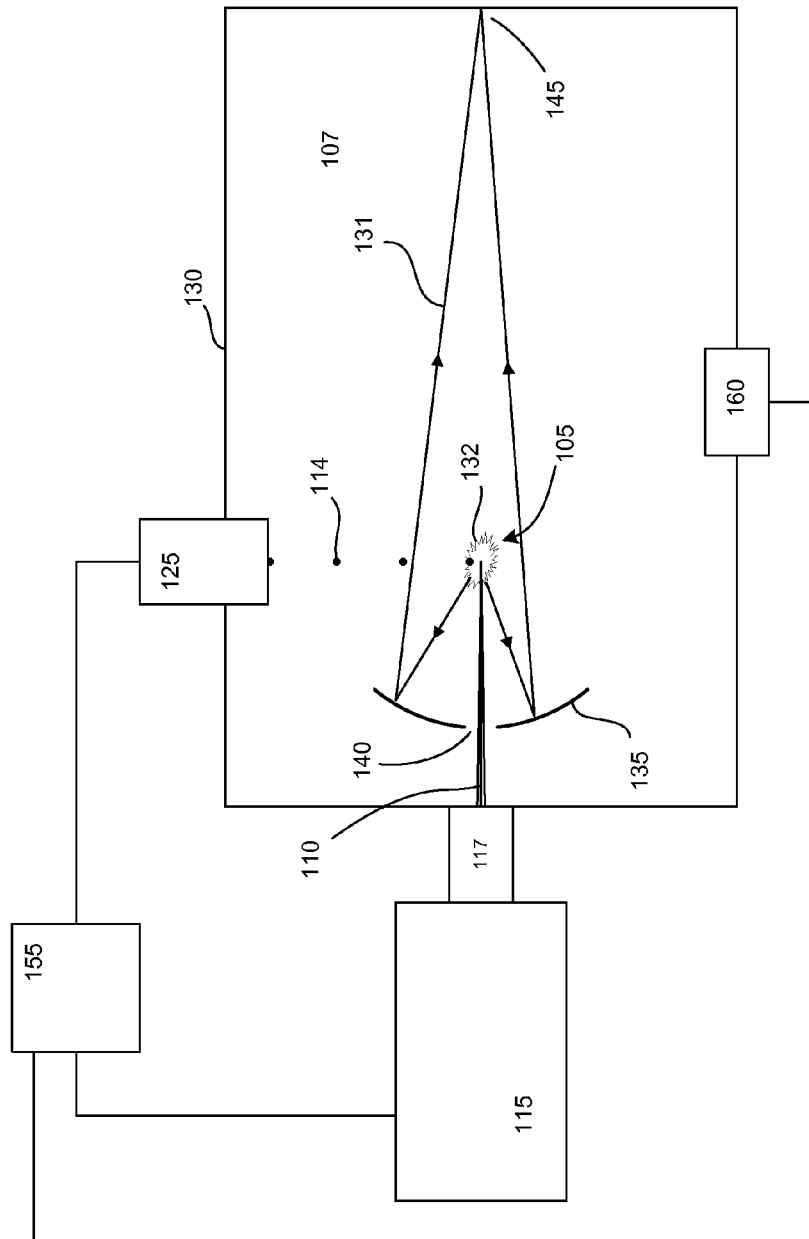


Fig. 1

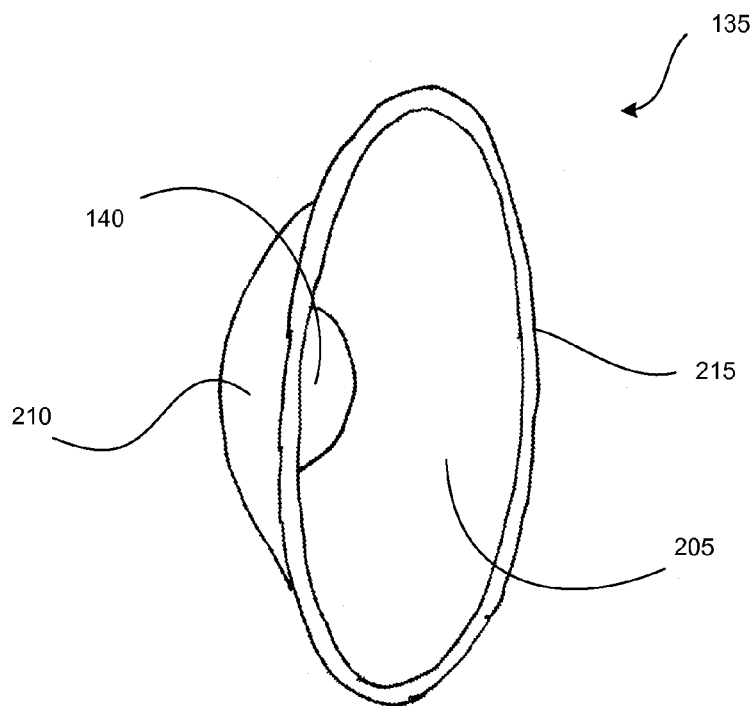


Fig. 2A

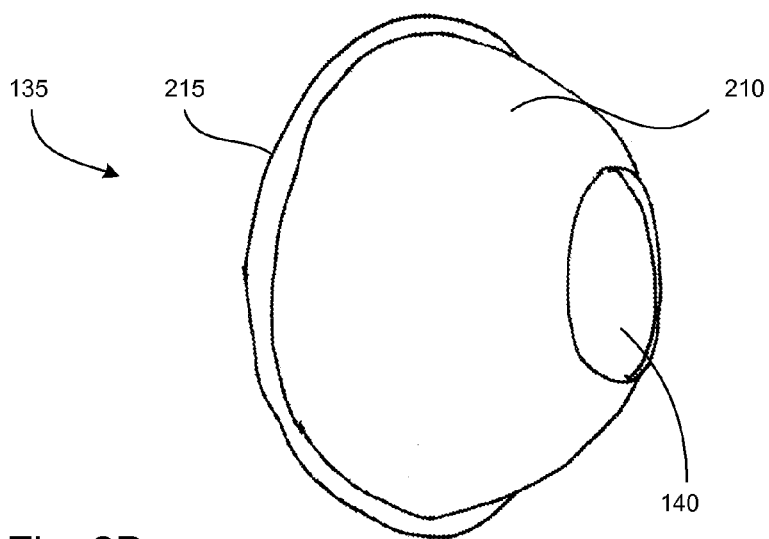


Fig. 2B

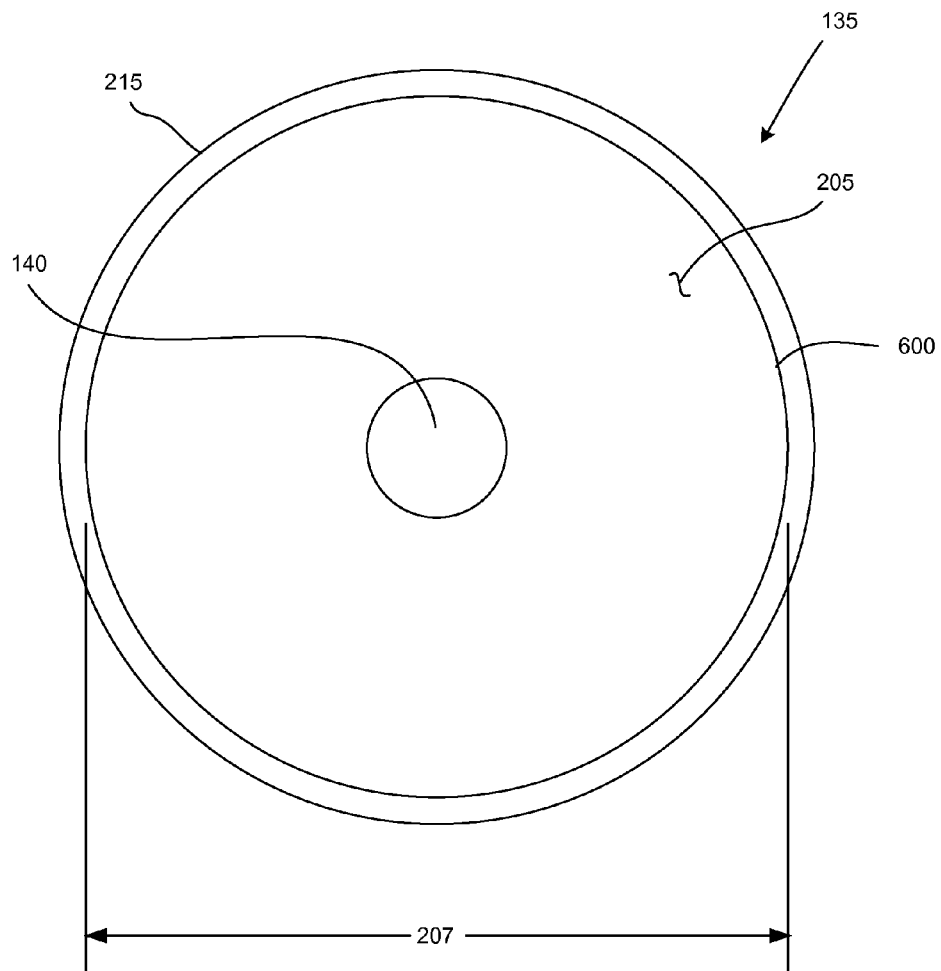
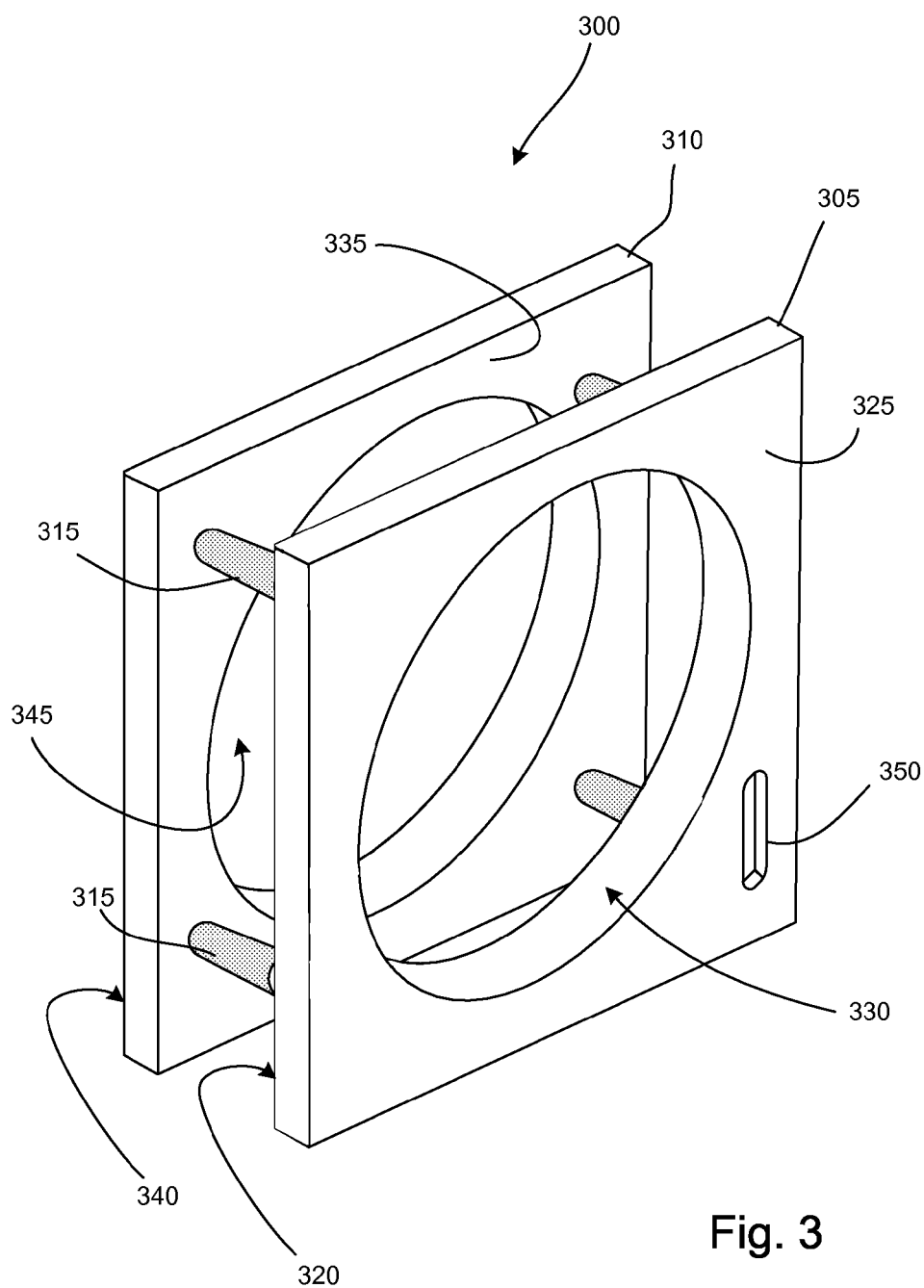


Fig. 2C



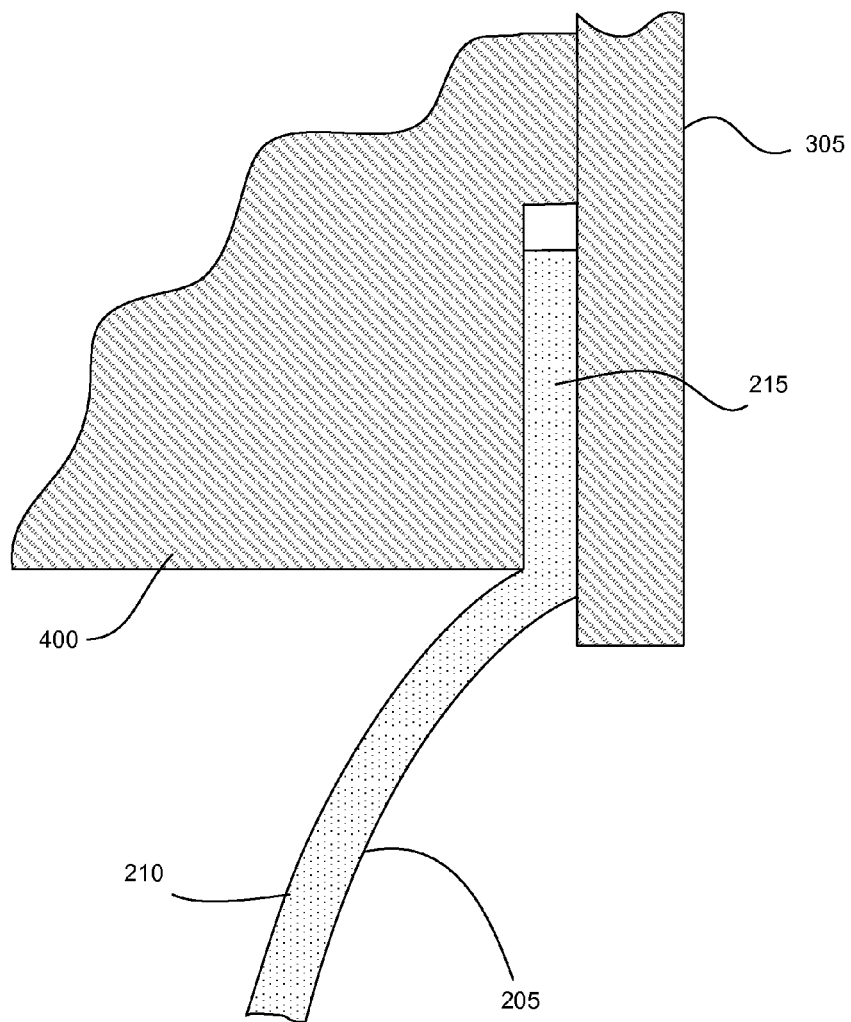


Fig. 4

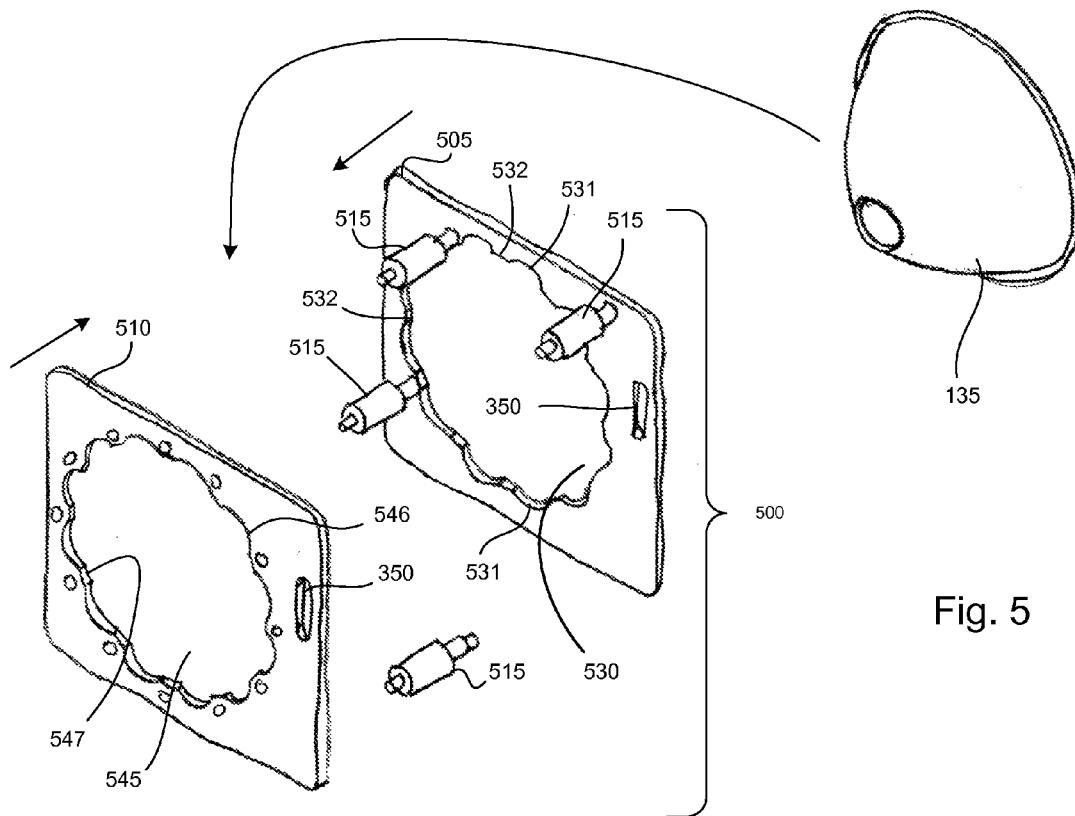


Fig. 5

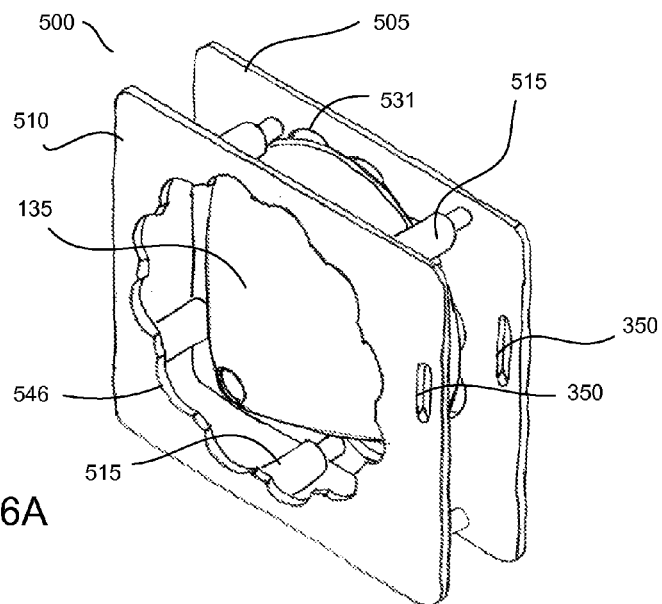


Fig. 6A

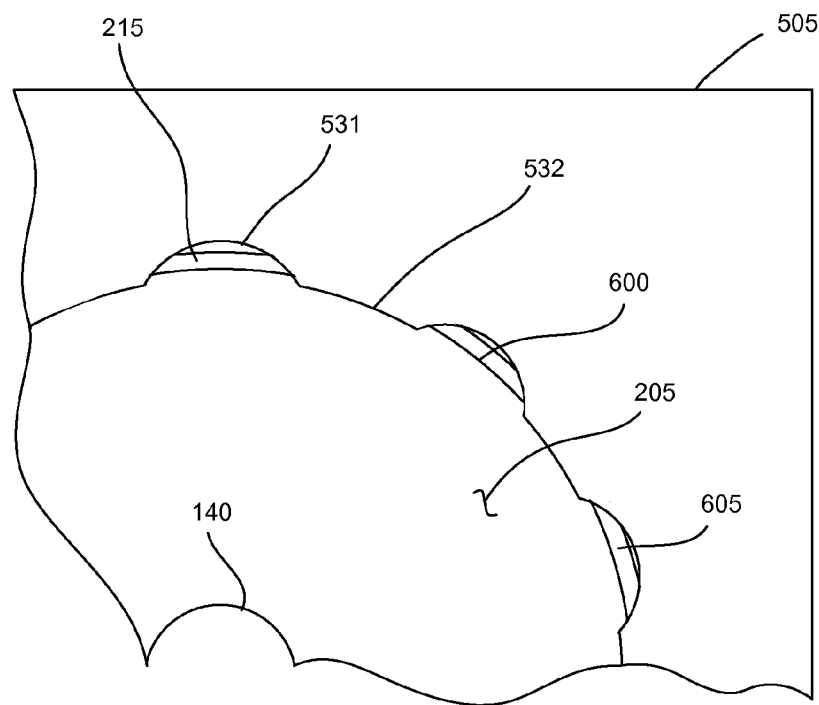


Fig. 6B

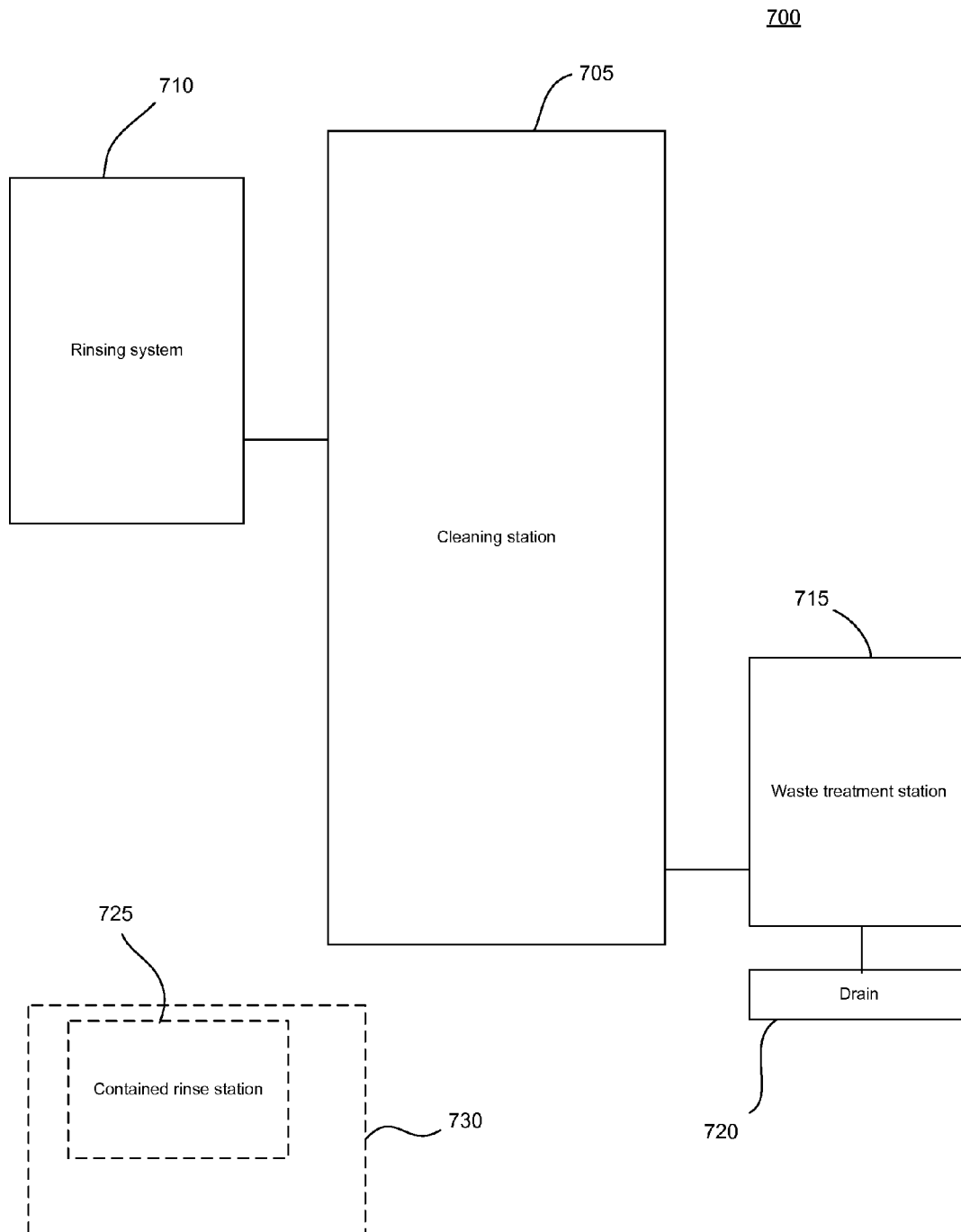


Fig. 7

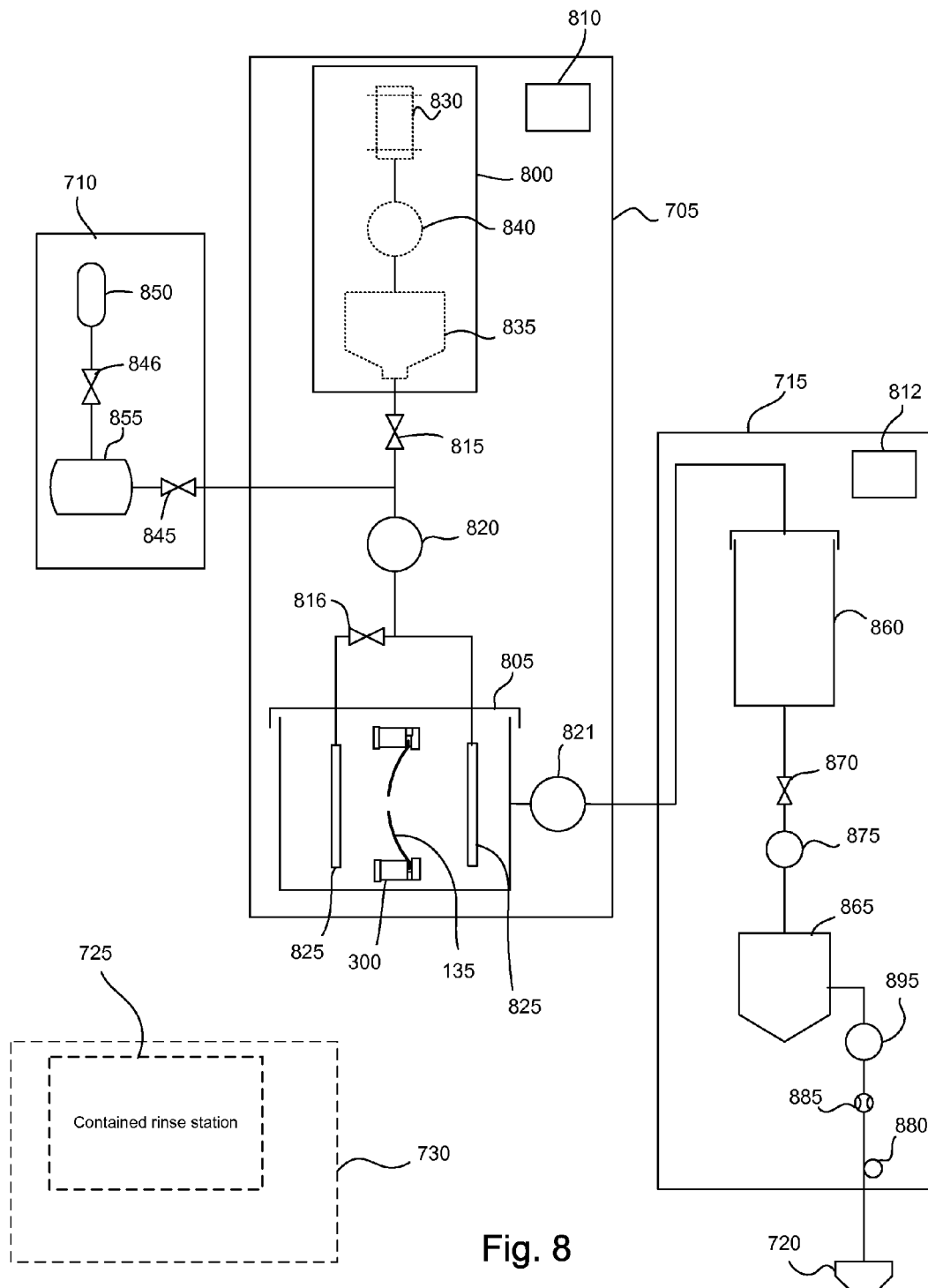


Fig. 8

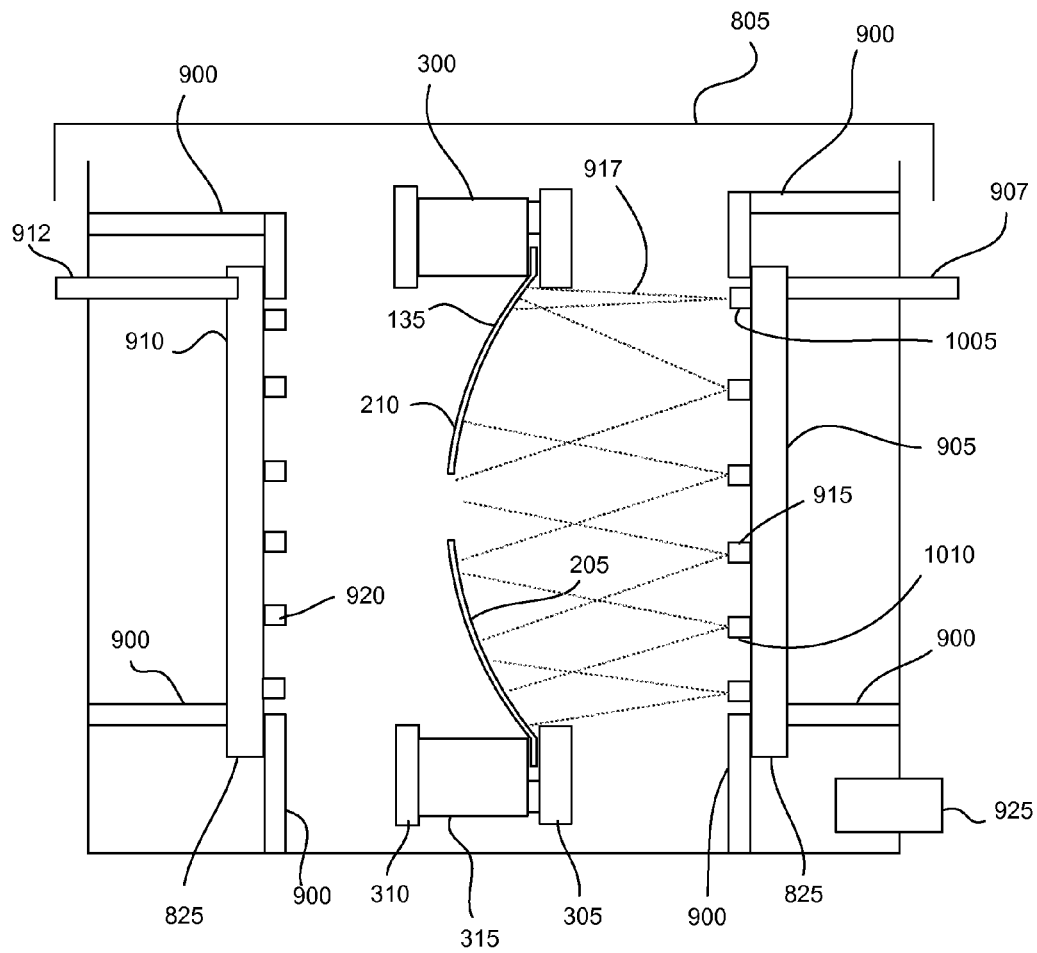


Fig. 9

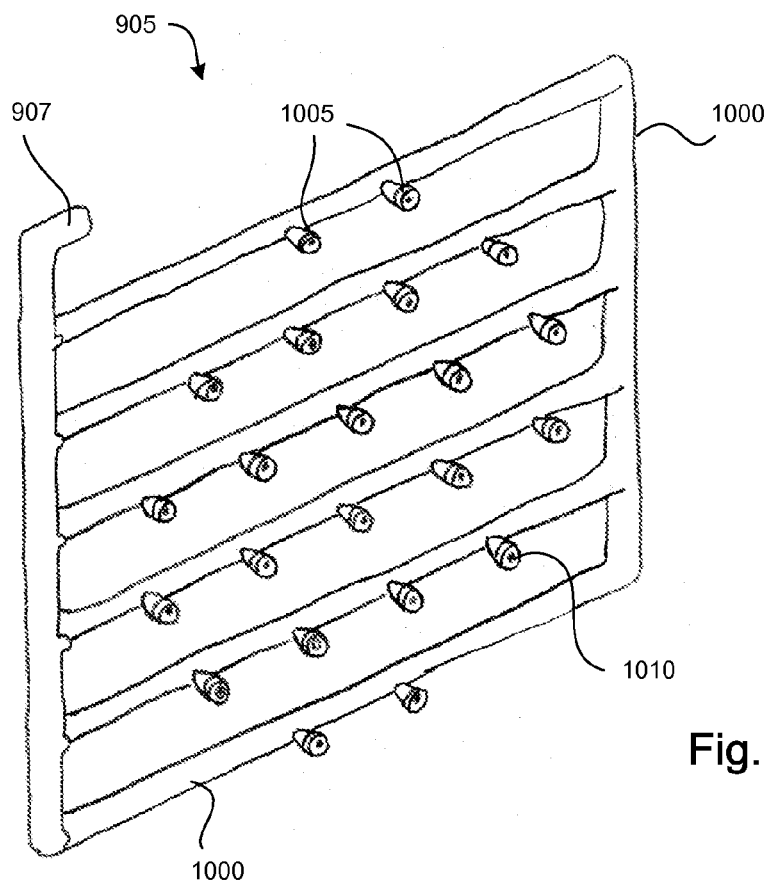


Fig. 10A

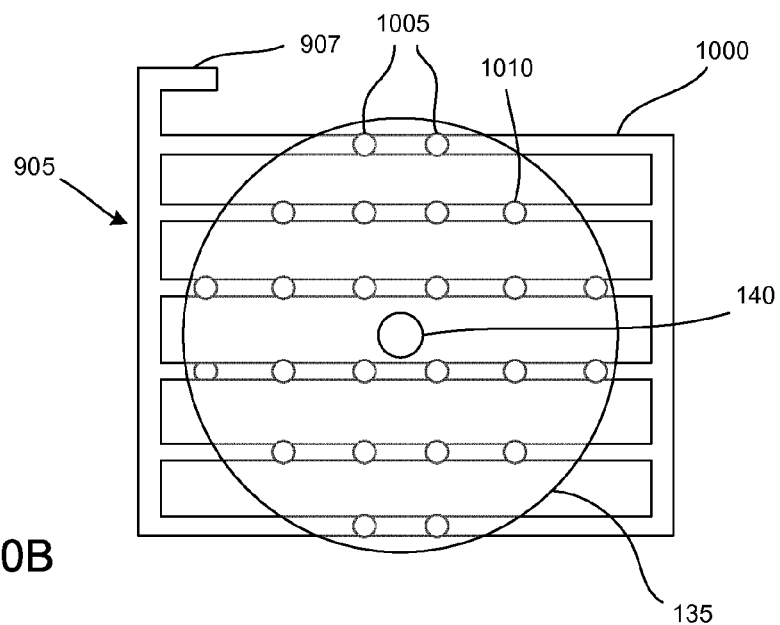


Fig. 10B

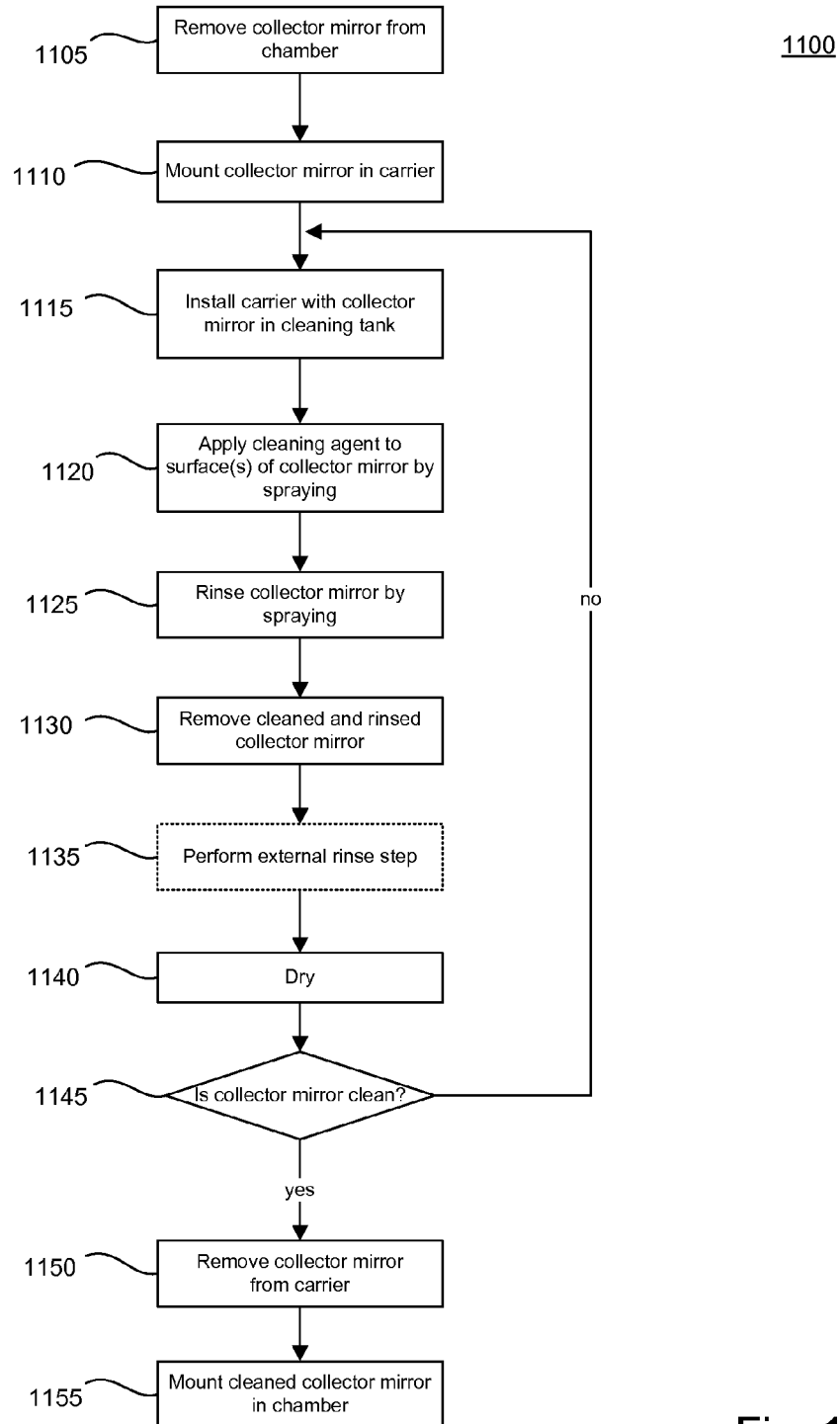
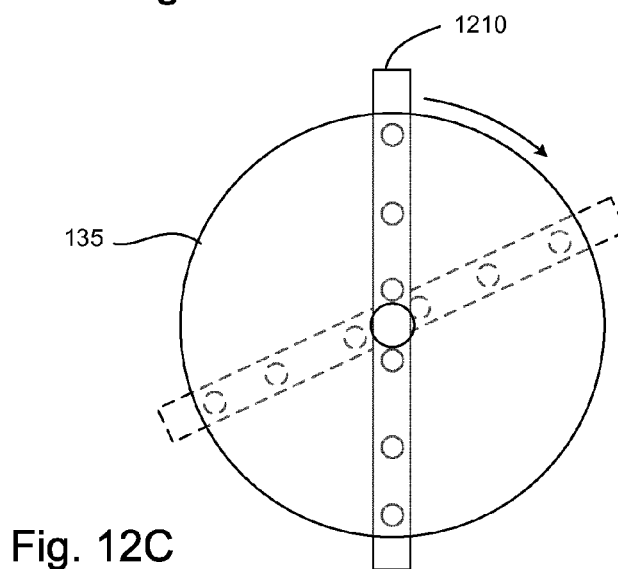
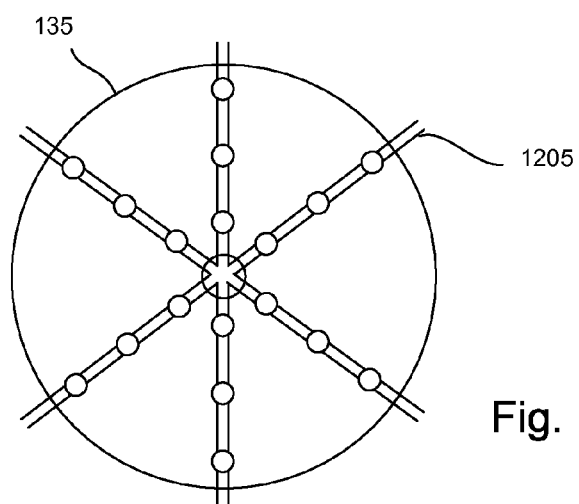
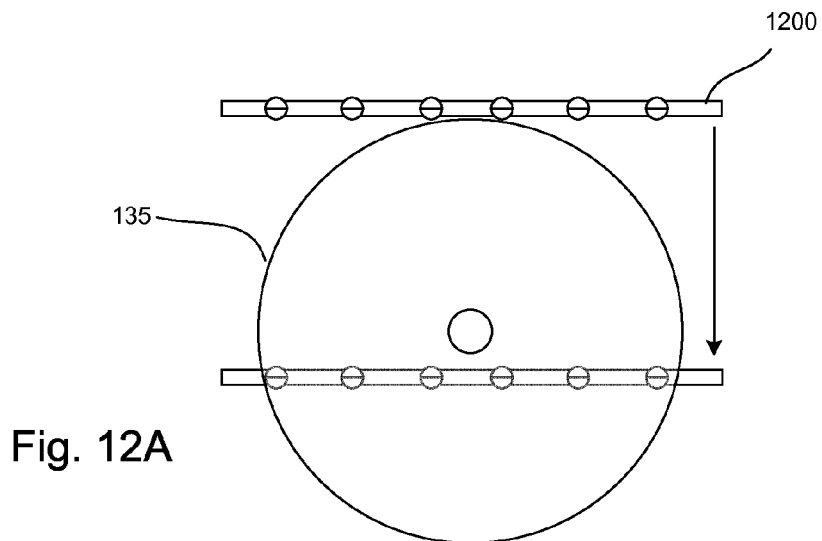


Fig. 11



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LIGHT COLLECTOR MIRROR CLEANING**TECHNICAL FIELD**

The disclosed subject matter relates to method for cleaning
a collector mirror that harnesses extreme ultraviolet light of
an extreme ultraviolet light source.

BACKGROUND

Extreme ultraviolet ("EUV") light is electromagnetic
radiation having wavelengths of around 50 nm or less and is
also sometimes referred to as soft x-rays. EUV light can be
used in photolithography processes to produce extremely
small features in substrates, for example, silicon wafers.
Methods to produce EUV light include, but are not necessar-
ily limited to, converting a material into a plasma state that
has an element, for example, xenon, lithium, or tin, with an
emission line in the EUV range. In one such method, often
termed laser produced plasma ("LPP"), the required plasma
can be produced by irradiating a target material, for example,
in the form of a droplet, stream, or cluster of material, with an
amplified light beam that can be referred to as a drive laser.
For this process, the plasma is typically produced in a sealed
vessel, for example, a vacuum chamber, and monitored using
various types of metrology equipment. The produced EUV
light is harnessed by a collector mirror, which outputs the
EUV light for use in a photolithography system.

SUMMARY

In some general aspects, a collector mirror of an extreme
ultraviolet light source is cleaned by removing the collector
mirror from a chamber of the extreme ultraviolet light source;
mounting the collector mirror to a carrier; inserting the carrier
with the collector mirror into a cleaning tank; applying a
cleaning agent to a reflective surface of the collector mirror by
spraying the cleaning agent through a plurality of nozzles
directed toward the collector mirror reflective surface until
the collector mirror reflective surface is clean; rinsing the
applied cleaning agent from the collector mirror reflective
surface; and drying the collector mirror reflective surface.

Implementations can include one or more of the following
features. For example, the collector mirror can be cleaned by
determining whether the collector mirror reflective surface is
clean. The collector mirror reflective surface can be deter-
mined to be clean by measuring a reflectivity of the collector
mirror reflective surface after drying; comparing the mea-
sured reflectivity of the collector mirror reflective surface to a
baseline reflectivity; and if the difference between the mea-
sured reflectivity and the baseline reflectivity is within 10% of
the baseline reflectivity, then determining that the collector
mirror reflective surface is clean. If the difference between the
measured reflectivity and the baseline reflectivity is within
5% of the baseline reflectivity, then the collector mirror
reflective surface can be determined to be clean. If the differ-
ence between the measured reflectivity and the baseline
reflectivity is within 1% of the baseline reflectivity, then the
collector mirror reflective surface can be determined to be
clean.

The collector mirror can be cleaned by also removing the
carrier from the cleaning tank, removing the collector mirror
from the carrier, and re-installing the collector mirror in the
chamber.

The cleaning agent can be applied to the collector mirror
reflective surface by spraying an acid solution through the
plurality of nozzles directed toward the collector mirror

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reflective surface until the collector mirror reflective surface
is clean. The acid solution can be sprayed by spraying hydro-
chloric acid through the plurality of nozzles directed toward
the collector mirror reflective surface. The hydrochloric acid
can have a concentration of at least 5% of hydrogen chloride
in water. The hydrochloric acid can be a concentrated grade
solution.

The cleaning agent can be applied to the collector mirror
reflective surface by moving one or more of the plurality of
nozzles and the collector mirror relative to each other while
the acid solution is sprayed through the plurality of nozzles
toward the collector mirror reflective surface.

The collector mirror reflective surface can be a multilayer
surface. The collector mirror reflective surface can include a
multilayer structure including, but not limited to, molybde-
num and silicon.

The collector mirror can be cleaned by also applying the
cleaning agent to a non-reflective surface of the collector
mirror by spraying the cleaning agent through a plurality of
nozzles directed toward the collector mirror non-reflective
surface until the collector mirror non-reflective surface is
clean; rinsing the applied cleaning agent from the collector
mirror non-reflective surface; and drying the collector mirror
non-reflective surface.

The cleaning agent can be applied to the collector mirror
reflective surface by spraying the cleaning agent through the
plurality of nozzles comprises overlapping the cleaning agent
applied from two or more nozzles at the collector mirror
reflective surface.

The cleaning agent can be applied to the collector mirror
reflective surface by spraying the cleaning agent through the
plurality of nozzles comprises overlapping the cleaning agent
applied from the plurality of nozzles at the collector mirror
reflective surface such that cleaning agent is applied to the
entire collector mirror reflective surface.

The cleaning agent can be sprayed through the plurality of
nozzles by directing the cleaning agent through one or more
nozzles that produce flat spray. The cleaning agent can be
sprayed through the plurality of nozzles by directing the
cleaning agent through one or more nozzles that produce
conical sprays.

The collector mirror can be cleaned by also removing the
collector mirror in the carrier from the cleaning tank; trans-
porting the collector mirror in the carrier to a clean facility;
and rinsing the collector mirror reflective surface with ultra-
high purity water in the clean facility. The collector mirror
reflective surface can be rinsed with ultra-high purity water by
spraying, with a spray apparatus, the ultra-high purity water
onto the collector mirror reflective surface while the collector
mirror and the spray apparatus move relative to each other
along a direction that is parallel with earth's gravity.

The collector mirror reflective surface can reflect light
having extreme ultraviolet wavelengths.

In another general aspect, a carrier for an extreme ultraviolet
light source collector mirror includes a front panel, a back
panel, and a plurality of posts. The front panel has an inner
surface and an outer surface opposite the inner surface, and
defines a through opening that has an edge having a plurality
of scallops, the scallops being positioned around a circum-
ference of the edge and being separated by arcs, where the
arcs define a circle that has a diameter that is less than a
diameter of the circular boundary of the reflective surface of
the collector mirror. The back panel has an inner surface that
faces the front panel and an outer surface opposite the inner
surface. The plurality of posts are configured to connect the
back panel to the front panel and to sandwich a flat rim around

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the circular boundary of the collector mirror between the inner surface of one of the panels and flanges of the posts.

Implementations can include one or more of the following features. For example, one or more of the front panel and the back panel can include handles defined by through openings. The front panel, the back panel, and the posts can each be made of a material that is impervious to cleaning solutions. One or more of the front panel, the back panel, and the posts can be made of plastics.

In another general aspect, a collector mirror of an extreme ultraviolet light source is cleaned by receiving a carrier, in which a collector mirror is mounted; inserting the carrier, in which the collector mirror is mounted, into a cleaning tank; applying a cleaning agent to a reflective surface of the collector mirror by spraying the cleaning agent through a plurality of nozzles directed toward the collector mirror reflective surface until the collector mirror reflective surface is clean; rinsing the applied cleaning agent from the collector mirror reflective surface; and drying the collector mirror reflective surface.

Implementations can include one or more of the following features. For example, prior to receiving the carrier, the collector mirror can be demounted (or removed) from a mount within a chamber of the extreme ultraviolet light source; the demounted collector mirror can be removed from the chamber; and the removed collector mirror can be mounted in the carrier.

DRAWING DESCRIPTION

FIG. 1 is a block diagram of an exemplary laser produced plasma (LPP) extreme ultraviolet (EUV) light source;

FIGS. 2A and 2B are perspective views of a collector mirror used in the light source of FIG. 1;

FIG. 2C is a side view of the collector mirror of FIGS. 2A and 2B;

FIG. 3 is a perspective view of a carrier that is configured to hold a collector mirror used in the light source of FIG. 1;

FIG. 4 is a side cross-sectional view of the carrier and the collector mirror showing the section at which the collector mirror is held in place by the carrier;

FIG. 5 is an exploded perspective view of an exemplary scalloped carrier for holding the collector mirror;

FIG. 6A is a perspective view of the carrier of FIG. 5 with the collector mirror held in place;

FIG. 6B is a side view of a section of the carrier of FIG. 5 with the collector mirror held in place and showing the scallops of the carrier relative to the collector mirror surface;

FIG. 7 is a block diagram of a cleaning apparatus for cleaning the collector mirror of the light source of FIG. 1;

FIG. 8 is a block diagram of an implementation of the cleaning apparatus of FIG. 7;

FIG. 9 is a block diagram of an exemplary cleaning tank for use in the cleaning apparatus of FIG. 8;

FIG. 10A is a perspective view of an exemplary fluid dispenser for use in the cleaning tank of FIG. 9;

FIG. 10B is a side view of the fluid dispenser of FIG. 10A showing its position relative to the collector mirror within the cleaning tank of FIG. 9;

FIG. 11 is a flow chart of a procedure for cleaning a collector mirror that is used in the light source of FIG. 1; and

FIGS. 12A-12C are side views of exemplary fluid dispensers showing their positions relative to the collector mirror within the cleaning tank of FIG. 9.

DESCRIPTION

Referring to FIG. 1, during operation of an LPP EUV light source 100, a collector mirror 135, including a reflective

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surface that is exposed to EUV radiation 131 produced at a target region 105, becomes dirty since it is exposed to debris released from the plasma or debris from a target mixture 114 at the target region 105. Thus, if the target mixture 114 includes tin, then the collector mirror 135 and its reflective surface becomes coated in tin, or compounds of tin, and the reflectivity, which can be considered to be the ratio of the energy of the EUV radiation reflected from the reflective surface to the energy possessed by the EUV radiation striking the reflective surface, of the reflective surface drops.

This disclosure relates to a process for effectively cleaning the collector mirror 135, including the EUV reflective surface, so that after cleaning using the process, the EUV reflective surface has a reflectivity that is within 10% of a baseline reflectivity, which can be the reflectivity of the EUV reflective surface prior to exposure to the debris during operation of the light source 100. This disclosure also relates to a carrier for mounting and transporting the collector mirror 135 after it is removed from a chamber 130 of the light source 100.

A brief description of the light source 100 is provided next, and following this description of the light source 100, details about the cleaning process and the carrier are provided.

The LPP EUV light source 100 is formed by irradiating the target mixture 114 at the target region 105 with an amplified light beam 110 that travels along a drive axis toward the target region 105. The drive axis of the amplified light beam 110 can be considered as the approximate center of the beam 110 or the general direction that the beam 110 is traveling because the beam 110 may be irregularly shaped or asymmetrical. The drive axis of the amplified light beam 110 can be considered the optical axis of the light beam 110.

The target region 105, which is also referred to as the irradiation site, is within an interior 107 of the vacuum chamber 130. When the amplified light beam 110 strikes the target mixture 114, a target material within the target mixture 114 is converted into a plasma state 132 that has an element with an emission line in the EUV range. The target mixture 114 in the plasma state therefore emits EUV radiation 131, and the EUV radiation 131 is harnessed by the collector mirror 135, which can be configured to redirect the emitted EUV radiation 131 toward an intermediate location 145, which is also called an intermediate focus of the collector mirror 135.

The created plasma has certain characteristics that depend on the composition of the target material within the target mixture 114. These characteristics can include the wavelength of the EUV radiation produced by the plasma, and the type and amount of debris released from the plasma.

The light source 100 includes a target material delivery system 125 that delivers, controls, and directs the target mixture 114 in the form of liquid droplets, a liquid stream, solid particles or clusters, solid particles contained within liquid droplets or solid particles contained within a liquid stream. The target mixture 114 includes the target material such as water, tin, lithium, xenon, or any material that, when converted to a plasma state, has an emission line in the EUV range. For example, the target material can be tin, which can be pure tin (Sn); a tin compound such as SnBr₄, SnBr₂, or SnH₄; a tin alloy such as a tin-gallium alloy, a tin-indium alloy, a tin-indium-gallium alloy, or any combination of these alloys. The target mixture 114 can also include impurities such as non-target particles. Thus, in the situation in which there are no impurities, the target mixture 114 is made up of only the target material. The target mixture 114 is delivered by the target material delivery system 125 into the interior 107 of the chamber 130 and to the target region 105.

The light source 100 includes a drive laser system 115 that produces the amplified light beam 110 due to a population

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inversion within a gain medium or mediums of the laser system **115**. The light source **100** includes a beam delivery system **117** between the laser system **115** and the target region **105** to direct the beam **110** from the laser system **115** to the target region **105**. The beam delivery system **117** can include a beam transport system, which receives the amplified light beam **110** from the laser system **115**, and steers and modifies the amplified light beam **110** as needed, and a focus assembly that receives the output from the beam transport system. The focus assembly focuses the beam **110** to the target region **105** and can also steer the beam **110** or adjust a position of the beam **110** relative to the target region **105**.

In some implementations, the drive laser system **115** can include one or more optical amplifiers, lasers, and/or lamps for providing one or more main pulses and, in some cases, one or more pre-pulses. Each optical amplifier includes a gain medium capable of optically amplifying the desired wavelength at a high gain, an excitation source, and internal optics. The optical amplifier may or may not have laser mirrors or other feedback devices that form a laser cavity. Thus, the drive laser system **115** produces an amplified light beam **110** due to the population inversion in the gain media of the laser amplifiers even if there is no laser cavity. Moreover, the laser system **115** can produce an amplified light beam **110** that is a coherent laser beam if there is a laser cavity to provide enough feedback to the laser system **115**. The term “amplified light beam” encompasses one or more of: light from the laser system **115** that is merely amplified but not necessarily a coherent laser oscillation and light from the laser system **115** that is amplified and is also a coherent laser oscillation (and can be referred to as a drive laser beam).

The optical amplifiers in the laser system **115** can include as a gain medium a filling gas that includes CO₂ and can amplify light at a wavelength of between about 9100 and about 11000 nm, and in particular, at about 10600 nm, at a gain greater than or equal to 1000. Suitable amplifiers and lasers for use in the laser system **115** can include a pulsed laser device, for example, a pulsed, gas-discharge CO₂ laser device producing radiation at about 9300 nm or about 10600 nm, for example, with DC or RF excitation, operating at relatively high power, for example, 10 kW or higher and high pulse repetition rate, for example, 50 kHz or more. The optical amplifiers in the laser system **115** can also include a cooling system such as water that can be used when operating the laser system **115** at higher powers.

The collector mirror **135** includes an aperture **140** to allow the amplified light beam **110** to pass through and reach the target region **105**. The collector mirror **135** can be, for example, an ellipsoidal mirror that has a primary focus at the target region **105** and a secondary focus at the intermediate location **145** (also called an intermediate focus) where the EUV light can be output from the light source **100** and can be input to, for example, an integrated circuit lithography tool (not shown). The collector mirror **135** has a reflective surface that reflects light having EUV wavelengths.

The light source **100** includes a master controller **155** connected to a laser control system of the drive laser system **115**, a beam control system of the beam delivery system **117**, and a target material control system of the target material delivery system **125**. The master controller **155** can therefore provide a laser position, direction, and timing correction signal to one or more of the laser control system and the beam control system.

The light source **100** can include one or more sensors or detectors **160** within the chamber **130** for providing outputs indicative of operating characteristics within the chamber, such as the position of a droplet, for example, relative to the

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target region **105** or reflected light from the target mixture **114**. The detectors **160** provide this output to the master controller **155**, which can, for example, compute a droplet position and trajectory from which a droplet position error can be computed either on a droplet by droplet basis or on average.

Thus, in summary, the light source **100** produces an amplified light beam **110** that is directed along the drive axis to irradiate the target mixture **114** at the target region **105** to convert the target material within the mixture **114** into plasma that emits light in the EUV range. The amplified light beam **110** operates at a particular wavelength (that is also referred to as a source wavelength) that is determined based on the design and properties of the laser system **115**. Additionally, the amplified light beam **110** can be a laser beam when the target material provides enough feedback back into the laser system **115** to produce coherent laser light or if the drive laser system **115** includes suitable optical feedback to form a laser cavity.

Referring to FIGS. 2A-2C, the collector mirror **135** includes the reflective surface **205** that harnesses the EUV radiation **131** produced at the target region **105**, a rear surface **210** that faces away from the target region **105** and need not be reflective, and a flat circumferential rim **215** that enables the collector mirror **135** to be held without touching the reflective surface **205**. The reflective surface **205** is a substrate coated with a material that reflects radiation having EUV wavelengths. For example, the reflective surface **205** can be a multilayer structure that includes silicon and molybdenum (and can optionally include other materials) applied to a substrate and the multilayer structure reflects at least 50% of radiation at 13.5 nanometers (nm). The reflective surface **205** can have protective capping layers such as, for example, silicon dioxide, silicon nitride, or other metals/oxides that do not significantly reduce EUV reflectivity. The substrate on which the reflective surface is applied can be made of silicon (Si), silicon carbide (SiC), Siliconized Silicon carbide (Si-SiC), or other materials like Al.

As discussed above, the collector mirror **135** becomes dirty after a period of use in the light source **100** because debris within the chamber **130** slowly coats the collector mirror **135**. The debris can coat the reflective surface **205**, which causes a reduction in the reflectivity of the collector mirror **135** at EUV wavelengths and thus causes a reduction in efficiency in operation of the light source **100**. The debris can also coat the rear surface **210** and the rim **215**.

Referring to FIG. 3, in order to clean the collector mirror **135**, it is removed from the chamber **130** of the light source **100** and placed into a carrier **300**, which is specially designed for the geometry of the collector mirror **135** and to enable efficient and adequate cleaning of the collector mirror **135** using a cleaning agent made of a composition that can break the bonds between the debris and the surface of the collector mirror **135** to thereby remove the debris from the collector mirror **135**. Moreover, the cleaning agent composition must not react with the material of the collector mirror **135**.

In one example, if the reflective surface **205** of the collector mirror **135** is a multilayer structure including silicon and molybdenum, the substrate is Si, and the target material is tin or a tin compound, then the cleaning agent can be hydrochloric acid, which reacts with the tin and dissolves it, but does not chemically react with or harm the multilayer structure. The hydrochloric acid can have any concentration of hydrogen chloride in water, such that it can have a concentration that varies from a lower value to a concentrated value, as long as the lower value enables adequate cleaning of the surface of the collector mirror **135**. In some implementations, the hydro-

chloric acid has a concentration of at least 5% hydrogen chloride in water. In other implementations, the hydrochloric acid is a concentrated solution; which means it can have a concentration of up to 37% hydrogen chloride in water.

The carrier **300** includes a front panel **305**, a back panel **310**, and a plurality of posts **315** that connect the back panel **310** to the front panel **305** and enable the collector mirror **135** to be sandwiched between the back panel **310** and the front panel **305**.

The front panel **305** has an inner surface **320** that faces the reflective surface **205** of the collector mirror **135** when the collector mirror **135** is inserted into the carrier **300**, and an outer surface **325** opposite the inner surface **320**. The front panel **305** defines a through opening **330** large enough to enable the cleaning agent to pass through and strike the reflective surface **205** of the collector mirror **135** when it is inserted into the carrier **300**. The shape of the through opening **330** can be any suitable shape that enables as much of the cleaning agent to pass while also enabling the collector mirror **135** to be adequately held in place within the carrier **300**. The shape of the through opening **330** of the carrier **300** is circular; and the diameter of the through opening **330** can be less than a diameter **207** (shown in FIG. 2C) of the circular boundary of the reflective surface **205** of the collector mirror **135**.

The back panel **310** has an inner surface **335** that faces the front panel and an outer surface **340** opposite the inner surface **335**. Though not required, the back panel **310** can also define a through opening **345** that is large enough to enable the cleaning agent to pass through and strike the rear surface **210** of the collector mirror **135** to thereby clean the rear surface **210**.

Referring also to FIG. 4, the plurality of posts **315** are configured to connect to the back panel **310** and to the front panel **305** and to sandwich the flat rim **215** of the collector mirror **135** between the inner surface **320** of the front panel **305** and flanges **400** of the posts **315**. For example, both ends of the posts **315** can have threads for receiving bolts that fit through the front panel **305** and the back panel **310** and the rim **215** can be received between the flange **400** of the post **315** and the inner surface **320** as the bolts are tightened to thereby secure the collector mirror **135** within the carrier **300**.

The front panel **305**, the back panel **310**, or both the front panel **305** and the back panel **310** can include handles **350** that enable someone to hold the carrier **300** and transport the carrier **300** with the mounted collector mirror **135**. The handles **350** can be blind openings or through openings.

The front panel **305**, the back panel **310**, and the posts **315** are made of a material that is impervious to the cleaning agent used. For example, in some implementations, these components of the carrier **300** are made of a plastic or a polymer, such as polypropylene or perfluoroalkoxy. In other examples, the carrier **300** materials can be resistant to acids or caustic substances that could be used as the cleaning agent.

Referring to FIGS. 5, 6A, and 6B, in another exemplary implementation of a carrier **500**, the front panel **505** has a through opening **530** that has scallops **531** positioned around a circumference of the edge of the opening **530** and being separated by arcs **532**. The arcs **532** define a circle that has a diameter that is less than the diameter **207** of the circular boundary **600** of the reflective surface **205** of the collector mirror **135**. In this implementation, the back panel **510** also has a through opening **545** that has scallops **546** positioned around a circumference of the edge of the opening **545** and separated by arcs **547**.

The scallops **531** enable more of the cleaning agent (or rinsing agent) used during the cleaning procedure to reach the reflective surface **205** of the collector mirror **135** when com-

pared with the circular through opening **330** of the carrier **300**. In particular, areas **605** of the rim **215** are exposed in the regions of the scallops **531** when the collector mirror **135** is mounted within the carrier **500**; and because of this, fluid sprayed toward the reflective surface **205** of the collector mirror **135** is able to reach the reflective surface **205** at angles that are tangential to the circumference of the boundary **600** to enable more of the fluid to reach the portions of the reflective surface **205** closest to the rim **215**.

Referring to FIG. 7, the carrier **300** (or **500**) is used to hold the collector mirror **135** while it is transported to and held in place in a cleaning apparatus **700**. The cleaning apparatus **700** generally includes a cleaning station **705** in which the carrier **300** or **500** is mounted to enable cleaning and rinsing of the collector mirror **135**, as detailed below. The cleaning apparatus **700** also includes a rinsing system **710** coupled in to the cleaning station **705** to provide a rinsing process for the collector mirror **135**. Additionally, because the cleaning agent used can be toxic to animals and plants or can be a controlled substance, the cleaning apparatus **700** can also include a waste treatment station **715** that removes the used cleaning agent and treats it for proper disposal or reuse prior to removal through a drain **720**.

The cleaning apparatus **700** can further include a self-contained rinsing station **725** that is separate from the cleaning station **705** and is within a clean environment, for example, within a cleanroom **730**, which is an environment that has a controlled (and often lower) level of environmental pollutants such as dust, airborne microbes, aerosol particles, and chemical vapors. For example, the cleanroom **730** can be configured to allow no particles larger than 0.5 μm in diameter and only a certain number of particles smaller than 0.3 μm per cubic meter. The rinsing station **725** can include its own rinsing fluid dispenser, which can be manually or automatically operated to project an ultra-high pure rinsing agent to the collector mirror **135** after the mirror **135** has been cleaned, rinsed, and dried using the cleaning station **705**. The ultra-high pure rinsing agent can be ultra-high purity water. The rinsing fluid dispenser can be moved relative to the collector mirror **135** across the surface of the mirror **135** to be rinsed.

In some implementations, the components of the cleaning apparatus **700** can be kept at ambient temperature and ambient pressure. However, it may be beneficial to adjust the temperature and/or pressure at one or more of the components of the cleaning apparatus **700** depending on the cleaning agent that is used and the physical characteristics of the collector mirror **135**. For example, the cleaning station **705**, or components of the cleaning station **705** can be held at a temperature above ambient temperature.

In implementations in which the reflective surface **205** of the collector mirror **135** includes a multi-layer coating made of Si and Mo, the components of the cleaning station **705** can be held at a temperature below 50° C., to reduce the possibility of damage to the coatings of the reflective surface **205** of the collector mirror **135**.

In other implementations, for example, if the reflective surface **205** of the collector mirror **135** includes a high temperature multi-layer coating (which has a SiN interdiffusion barrier), then the components of the cleaning station **705** could be held at a temperature greater than ambient temperature, or up to about 100° C. Thus, in these examples, it is possible that a temperature higher than ambient temperature could improve cleaning. If the cleaning agent includes hydrochloric acid (HCl), then it may not be necessary or any more effective to clean the collector mirror **135** at a temperature other than ambient temperature. On the other hand, if the cleaning station **705** uses other cleaning agents such as acetic

acid, then it might be beneficial to maintain components of the cleaning station 705 at a temperature greater than the ambient temperature to clean the collector mirror 135.

One exemplary implementation of the cleaning apparatus 700 is shown in FIG. 8. In this implementation, the cleaning station 705 includes a source 800 for providing the cleaning agent to a cleaning tank 805 in which the carrier 300 with the collector mirror 135 is housed. The cleaning station 705 also includes a controller 810 that can be used for automated operation of components within the source 800 and/or the tank 805 as well as fluid control devices, such as one or more valves 815, 816 and one or more pumps 820, 821 for transporting the cleaning agent from the source 800 to the tank 805. The cleaning station 705 also includes a fluid dispenser 825 that is placed within the tank 805 and faces the surface or surfaces of the collector mirror 135 to transport fluids from other parts of the apparatus 700 toward the surface or surfaces of the collector mirror 135. In some implementations, the fluid dispenser 825 is stationary relative to the collector mirror 135 during the cleaning process and thus the dispenser 825 is held in place within the tank 805 using a suitable mounting system. However, in other implementations, it might be possible to move the fluid dispenser 825 and the collector mirror 135 relative to each other (for example, by moving the fluid dispenser 825 while holding the collector mirror 135 stationary).

The source 800 includes a storage container 830 that holds and stores the cleaning agent and is fluidly connected to a storage tank 835. A pump 840 can be used to control the flow rate of the cleaning agent from the storage container 830 toward the storage tank 835.

The cleaning apparatus 700 also includes the rinsing system 710 fluidly coupled in to the cleaning station 705 by way of a rinse valve 845 to provide a rinsing process for the collector mirror 135. Thus, during cleaning steps of the process, as detailed below, the valve 815 is open and the rinse valve 845 is closed and during rinsing steps, the valve 815 is closed and the rinse valve 845 is open. The rinsing system 710 includes a supply 850 that is fluidly coupled to a tank 855 through a valve 846. The rinsing system 710 can employ any suitable rinsing agent, as long as the rinsing agent is able to remove the cleaning agent from the surfaces of the collector mirror 135 and keep streaks on the surface of the collector mirror 135 low or to a minimum. In some implementations, the rinsing agent is deionized water. In other implementations, the rinsing agent is isopropyl alcohol, acetone, methanol, or ethanol.

The waste treatment station 715, though not required for operation of the cleaning apparatus 700, is used to properly dispose of or reuse the cleaning agent, which can be a controlled substance. The waste treatment station 715, if included in the cleaning apparatus 700, includes an accumulation tank 860 that receives waste material output from the tank 805 through the pump 821 and stores the waste material until it can be properly treated by a treatment tank 865. The treatment tank 865 is fluidly coupled to the accumulation tank 860 by way of a valve 870 and a pump 875 that control how much waste material is directed to the treatment tank 865.

One or more of the cleaning station 705 and the waste treatment station 715 can include diagnostic devices that measure characteristics of the material. For example, the station 715 includes diagnostic devices that measure characteristics of the treated material that is output from the tank 865 toward the drain 720 by way of a drain valve and a drain pump 895. For example, diagnostic devices include a pH meter 880 that measures the acidity or alkalinity (pH) of the treated material, and a flow meter 885 that measures the flow rate of

the treated material flowing from the treatment tank 865 toward the drain 720. Additionally, the waste treatment station 715 can also include a separate or dedicated controller 812 that monitors the diagnostic devices or controls the operation of the fluid control devices such as the valve 870 and the pump 875 within the station 715. The controller 812 can be connected to the controller 810 to provide feedback to the cleaning station 705 regarding the waste material characteristics.

Referring also to FIG. 9, the tank 805 houses the carrier 300, in which the collector mirror 135 is held, and the fluid dispenser 825 that faces the surface or surfaces 205, 210 of the collector mirror 135. The fluid dispenser 825 transports the fluid from other parts of the apparatus 700 toward the surface or surfaces 205, 210 of the collector mirror 135. The fluid dispenser 825 can be stationary relative to the collector mirror 135 during the cleaning process and thus, in this case, the dispenser 825 is held in place within the tank 805 using a mounting system 900, which can use frictional engagement or mechanical attachment devices such as screws, bolts, and nuts to hold the dispenser 825 in place. In other implementations that are discussed below, the fluid dispenser 825 and the collector mirror 135 are moved relative to each other within the tank, for example, by moving the fluid dispenser 825 while holding the collector mirror 135 stationary.

The fluid dispenser 825 includes a front fluid dispenser 905 that faces the reflective surface 205 of the collector mirror 135. If the rear surface 210 is to be cleaned simultaneously with the reflective surface 205 of the collector mirror 135, then the fluid dispenser 825 can also include a back fluid dispenser 910 that faces the rear surface 210 of the collector mirror 135. The front fluid dispenser 905 includes a plurality of spray nozzles 915 that face the reflective surface 205 and the back fluid dispenser 910 includes a plurality of spray nozzles 920 that face the rear surface 210 of the collector mirror 135.

Referring also to FIGS. 10A and 10B, the front fluid dispenser 905 includes hollow tubing 1000 through which fluid such as the cleaning agent or a rinsing fluid is flowed; the hollow tubing 1000 is fluidly connected by way of a fluid input 907 to the pump 820, which receives fluid from either the cleaning agent source 800 or the rinsing system 710. The back fluid dispenser 910 also includes hollow tubing through which fluid such as the cleaning agent or rinsing fluid is flowed; the hollow tubing is fluidly connected by way of a fluid input 912 to the pump 820. The fluid that flows from the input 907 through the hollow tubing of the front fluid dispenser 905 is forced through the spray nozzles 915, which disperse the fluid into a spray 917 directed at the reflective surface 205 of the collector mirror 135. Similarly, the fluid that flows from the input 912 through the hollow tubing of the back fluid dispenser 910 is forced through the spray nozzles 920, which disperse the fluid into a spray directed at the rear surface 210 of the collector mirror 135.

The direction and characteristics of the fluid flow from the spray nozzles 915 and 920 toward the collector mirror 135 can be adjusted, depending on the distance of the fluid dispensers 905, 910 from the collector mirror 135, the amount of dirt on the collector mirror 135, the geometries, and the materials used on the collector mirror 135. For example, the velocity, flow rate, direction, mass, shape, and/or pressure of the fluid flow can be adjusted (for example, increased or decreased), depending on these factors. The direction of the fluid flow from the nozzles 915, 920 can be set up to be at varying angles relative to the surface of the collector mirror 135 when it strikes the surface. The spray pattern imparted by

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the fluid dispensers **905**, **910** can be varied by changing the arrangement, type, or these other characteristics of the spray nozzles.

The tank **805** is enclosed so that waste fluid, which is any spray emitted from the fluid dispensers **905**, **910** that strikes the interior of the tank or spray that drips from the collector mirror **135** to the bottom of the tank, is contained within the tank **805** until being removed through an output fluid port **925**. And, if waste treatment is needed, the output fluid port **925** directs the waste fluid to the waste treatment station **715** prior to being directed to the drain **720**.

The nozzles **915** of the front fluid dispenser **905** are geometrically arranged so that the spray **917** of the fluid output from a particular nozzle **915** overlaps at the reflective surface **205** of the collector mirror **135** with the spray **917** of the fluid output from a nearby nozzle **915**. This sort of geometric arrangement can be employed for the nozzles **920** of the back fluid dispenser **910** such that the spray of the fluid output from each nozzle **920** overlaps at the rear surface **210** with the spray of the fluid output from a nearby nozzle **920**. One or more of the nozzles **915** of the front fluid dispenser **905** can produce flat sprays and one or more of the nozzles **915** of the front fluid dispenser **905** can produce conical sprays. For example, in the implementation shown in FIGS. **9**, **10A**, and **10B**, the top-most nozzles **1005** produce a flat spray while the rest of the nozzles **1010** produce conical sprays. The spray nozzles **920** of the back fluid dispenser **910** can have similar designs, and can include one or more nozzles that produce flat sprays and one or more nozzles that produce conical sprays.

By applying the cleaning agent using a spraying technique using the spray nozzles **915**, **920**, agitation is employed to further assist in removing the debris from the surface of the collector mirror **135**.

Referring to FIG. **11**, a procedure **1100** is performed for cleaning the collector mirror **135**.

Initially, the collector mirror **135** is removed from the chamber **130** of the light source **100** (step **1105**). Typically, in order to remove the collector mirror **135** from the chamber **130** the collector mirror **135** must be disconnected, removed, or demounting from a mount designed to hold the collector mirror **135** within the chamber. After removal from the chamber **130**, the collector mirror **135** is mounted within the carrier **300** (step **1110**). In one implementation of mounting (step **1110**), the back panel **310** of the carrier **300** is rested with its outer surface **340** facing down, with the posts **315** already attached to the back panel **310**, and the rim **215** of the collector mirror **135** is rested on top of the flanges **400** of the posts **315** so that the rear surface **210** of the collector mirror **135** faces the inner surface **335** of the back panel **310**. Next, the front panel **305** is rested on the collector mirror **135** so that the rim **215** is sandwiched between the flanges **400** and the inner surface **320** of the front panel **305** and the other sides of the posts **315** are suitably attached to the front panel **305**.

Next, the carrier **300** that holds the collector mirror **135** is installed within the cleaning tank **805** using the mounting system **900** (step **1115**). The carrier **300** can be moved with the aid of the handles **350**—thus, one or more people can hold the carrier **300** at the handles **350** to transport the carrier **300** from the location at which the collector mirror **135** is mounted into the cleaning tank **805**.

Cleaning agent is applied to one or more surfaces (for example, the reflective surface **205**) of the collector mirror **135** (step **1120**). In some implementations, this is done by opening the valve **815**, while making sure that rinse valve **845** is closed, pumping the cleaning agent from the storage tank **835** using the pump **820** to the fluid dispenser **825** (for example, the front fluid dispenser **905**) to thereby flow the

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cleaning agent through the spray nozzles of the fluid dispenser **825** to cause the cleaning agent to be sprayed onto the surface of the collector mirror **135**. For example, the cleaning agent is directed through the spray nozzles **915** of the front fluid dispenser **905** toward the reflective surface **205** of the collector mirror **135**. As noted previously, in this particular example, the fluid dispenser **825** and the carrier **300** and collector mirror **135** are stationary relative to each other during this step. However, it is possible that they can be moved relative to each other while the cleaning agent is applied to the surface of the collector mirror **135**, as shown in the alternative implementations of FIGS. **12A-12C**.

After the cleaning agent is applied to the surface or surfaces of the collector mirror **135** (step **1120**), then the collector mirror **135** surface or surfaces are rinsed (step **1125**). In order to rinse the surface of the collector mirror **135** (step **1125**), the valve **815** is closed (to prevent any cleaning agent from reaching the collector mirror **135**) and the rinse valve **845** is opened to thereby fluidly couple the tank **855** that holds the rinsing agent to the pump **820** and thus to the fluid dispenser **825**. In this way, the pump **820** forces the rinsing agent through the fluid dispenser **825** toward the surface or surfaces of the collector mirror **135** to remove any remaining cleaning agent or other particles from the surface or surfaces of the collector mirror **135**.

After the collector mirror **135** is cleaned (step **1120**) and rinsed (step **1125**), it is removed from the tank **805** (step **1130**). To facilitate removal, a person can pick up the carrier **300** at the handles **350**.

The collector mirror **135** is rinsed again in the self-contained rinsing station **725** (step **1130**) by applying ultra-high purity rinsing agent to the cleaned surface or surfaces of the collector mirror **135**. The ultra-high purity rinsing agent can be applied using a fluid dispenser such as the fluid dispenser **825** or it can be applied using another spray nozzle arrangement that is moved manually or automatically relative to the surface of the collector mirror **135** while the ultra-high purity rinsing agent is forced through the spray nozzles of the arrangement. After this external and clean rinsing step is completed, then the surfaces of the collector mirror **135** are dried (step **1140**) with a nitrogen air gun or an air knife.

The collector mirror **135** is tested to determine whether it is adequately clean (step **1145**), and if it is not adequately clean, then it is re-installed in the cleaning tank (step **1115**) for additional cleaning using the steps of the procedure **1100** detailed above. Testing of the collector mirror at step **1145** can involve measuring the reflectivity of the surface that has been cleaned and comparing this measured reflectivity to a baseline reflectivity, which can be the reflectivity of the surface that was measured prior to exposure to the debris or operation within the light source **100** or it can be a pre-determined reflectivity that is needed for efficient operation of the light source **100**. For example, if the measured reflectivity is within 10% of the baseline reflectivity (at step **1145**), then it is determined that the collector mirror **135** has been adequately cleaned. In other implementations, the collector mirror **135** is considered to be clean (at step **1145**) if the measured reflectivity is within 5% of the baseline reflectivity. In other implementations, the collector mirror **135** is considered to be clean (at step **1145**) if the measured reflectivity is within 1% of the baseline reflectivity.

If it is determined that the collector mirror **135** is adequately clean (step **1145**), then the mirror **135** can be removed from the carrier **300** (step **1150**) and re-mounted within the chamber **130** of the light source **100** (step **1155**). The procedure **1100** can be repeated whenever efficiency (or other suitable characteristics, such as the reflectivity of the

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reflective surface of the collector mirror **135**) of the light source **100** drops below a pre-determined threshold.

In some implementations, all of the steps, including removal, mounting, cleaning, rinsing, drying, and remounting, of the procedure **1100** are performed by a single entity or organization. However, the procedure **1100** can be performed at different entities, organizations, or locations. For example, the operator of the LPP EUV light source **100** might be tasked with performing the initial steps of removal from the chamber (step **1105**) and mounting in the carrier (step **1110**) and/or the latter steps of removal from the carrier (step **1150**) and remounting within the chamber (step **1155**). A separate non-operating entity who is not the operator of the light source **100** might be tasked with the cleaning, rinsing, testing, and drying steps (for example, steps **1115-1145**) of the procedure **1100**. In this particular implementation, the separate entity would receive the carrier, in which the collector mirror is mounted from the operator of the light source **100** prior to performing the steps **1115-1145** and would send the collector mirror (mounted in the carrier) back to the light source operator after it has been adequately cleaned.

As mentioned above, and with reference to FIGS. **12A-12C**, other designs for the fluid dispenser **825** are possible. For example, as shown in FIG. **12A**, the fluid dispenser **825** is a linear array **1200** of nozzles that are moved relative to the surface of the collector mirror **135** during cleaning and rinsing steps that take place during the procedure **1100**. As shown in FIG. **12B**, the fluid dispenser **825** is a radial array **1205** of nozzles that can be stationary relative to the surface of the collector mirror **135**. As shown in FIG. **12C**, the fluid dispenser **825** is a radial and linear array **1210** of nozzles that are moved (for example, rotated) relative to the surface of the collector mirror **135**. Other arrangements for the spray nozzles and the fluid dispenser **825** are possible, as long as the fluid applied to the surface of the collector mirror **135**. Other implementations are within the scope of the following claims.

What is claimed is:

1. A method for cleaning a collector mirror of an extreme ultraviolet light source, the method comprising:
 - removing the collector mirror from a chamber of the extreme ultraviolet light source;
 - mounting the collector mirror to a carrier;
 - inserting the carrier with the collector mirror into a cleaning tank;
 - applying a cleaning agent to a reflective surface of the collector mirror by spraying the cleaning agent through a plurality of nozzles directed toward the collector mirror reflective surface until the collector mirror reflective surface is clean;
 - rinsing the applied cleaning agent from the collector mirror reflective surface;
 - drying the collector mirror reflective surface;
 - removing the carrier from the cleaning tank;
 - removing the collector mirror from the carrier; and
 - re-installing the collector mirror in the chamber.
2. The method of claim 1 further comprising determining whether the collector mirror reflective surface is clean by comparing a measured reflectivity of the collector mirror reflective surface to a baseline reflectivity.
3. The method of claim 2 wherein determining whether the collector mirror reflective surface is clean comprises:
 - if the measured reflectivity is within 10% of the baseline reflectivity, then determining that the collector mirror reflective surface is clean.
4. The method of claim 3 wherein if the difference between the measured reflectivity and the baseline reflectivity is

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within 5% of the baseline reflectivity, then the collector mirror reflective surface is determined to be clean.

5. The method of claim 3 wherein if the difference between the measured reflectivity and the baseline reflectivity is within 1% of the baseline reflectivity, then the collector mirror reflective surface is determined to be clean.

6. The method of claim 1 wherein applying the cleaning agent to the collector mirror reflective surface comprises spraying an acid solution through the plurality of nozzles directed toward the collector mirror reflective surface until the collector mirror reflective surface is clean.

7. The method of claim 6 wherein spraying the acid solution comprises spraying hydrochloric acid through the plurality of nozzles directed toward the collector mirror reflective surface.

8. The method of claim 7 wherein the hydrochloric acid has a concentration of at least 5% of hydrogen chloride in water.

9. The method of claim 7 wherein the hydrochloric acid is a concentrated solution comprising a concentration of up to 37% hydrogen chloride in water.

10. The method of claim 6 wherein applying the cleaning agent to the collector mirror reflective surface comprises moving one or more of the plurality of nozzles and the collector mirror relative to each other while the acid solution is sprayed through the plurality of nozzles toward the collector mirror reflective surface.

11. The method of claim 1 wherein the collector mirror reflective surface is a multilayer surface.

12. The method of claim 1 wherein the collector mirror reflective surface is a multilayer structure including molybdenum and silicon.

13. The method of claim 1 further comprising:

- applying the cleaning agent to a non-reflective surface of the collector mirror by spraying the cleaning agent through a plurality of nozzles directed toward the collector mirror non-reflective surface until the collector mirror non-reflective surface is clean;
- rinsing the applied cleaning agent from the collector mirror non-reflective surface; and
- drying the collector mirror non-reflective surface.

14. The method of claim 1 wherein applying the cleaning agent to the collector mirror reflective surface by spraying the cleaning agent through the plurality of nozzles comprises overlapping the cleaning agent applied from two or more nozzles at the collector mirror reflective surface.

15. The method of claim 1 wherein applying the cleaning agent to the collector mirror reflective surface by spraying the cleaning agent through the plurality of nozzles comprises overlapping the cleaning agent applied from the plurality of nozzles at the collector mirror reflective surface such that cleaning agent is applied to the entire collector mirror reflective surface.

16. The method of claim 1 wherein spraying the cleaning agent through the plurality of nozzles comprises directing the cleaning agent through one or more nozzles that produce flat spray.

17. The method of claim 1 wherein spraying the cleaning agent through the plurality of nozzles comprises directing the cleaning agent through one or more nozzles that produce conical sprays.

18. The method of claim 1 further comprising:

- removing the collector mirror in the carrier from the cleaning tank;
- transporting the collector mirror in the carrier to an environmentally-controlled facility; and

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rinsing the collector mirror reflective surface with ultra-high purity water in the environmentally-controlled facility.

19. The method of claim 18 wherein rinsing the collector mirror reflective surface with ultra-high purity water comprises spraying, with a spray apparatus, the ultra-high purity water onto the collector mirror reflective surface while the collector mirror and the spray apparatus move relative to each other along a direction that is parallel with earth's gravity.

20. The method of claim 1 wherein the collector mirror reflective surface reflects at least 50% of radiation at 13.5 nm.

21. A method for cleaning a collector mirror of an extreme ultraviolet light source, the method comprising:

demounting a collector mirror from a mount within a chamber of the extreme ultraviolet light source;

removing the demounted collector mirror from the chamber;

mounting the removed collector mirror in a carrier; receiving the carrier, in which the collector mirror is mounted;

inserting the carrier, in which the collector mirror is mounted, into a cleaning tank;

applying a cleaning agent to a reflective surface of the collector mirror by spraying the cleaning agent through a plurality of nozzles directed toward the collector mirror reflective surface until the collector mirror reflective surface is clean;

rinsing the applied cleaning agent from the collector mirror reflective surface; and

drying the collector mirror reflective surface.

22. The method of claim 18 wherein the environmentally-controlled facility allows no particles larger than 0.5 μm in diameter.

23. A method for cleaning a collector mirror of an extreme ultraviolet light source, the method comprising:

removing the collector mirror from a chamber of the extreme ultraviolet light source;

mounting the collector mirror to a carrier by placing the collector mirror between front and back panels of the carrier such that a flat rim around a circular boundary of the collector mirror is between the front and back panels; inserting the carrier with the collector mirror into a cleaning tank;

applying a cleaning agent to a reflective surface of the collector mirror by spraying the cleaning agent through a plurality of nozzles directed toward the collector mirror reflective surface until the collector mirror reflective surface is clean;

rinsing the applied cleaning agent from the collector mirror reflective surface; and

drying the collector mirror reflective surface.

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24. The method of claim 2, wherein the baseline reflectivity is a reflectivity of the collector mirror reflective surface that is measured prior to exposure to debris during operation within the extreme ultraviolet light source.

25. A method for cleaning a collector mirror of an extreme ultraviolet light source, the method comprising:

accessing a collector mirror that is positioned within a chamber of the extreme ultraviolet light source so that a primary focus of the collector mirror is at a target region of the chamber, the target region receiving an amplified light beam and a target mixture;

removing the accessed collector mirror from the chamber of the extreme ultraviolet light source;

mounting the collector mirror to a carrier;

inserting the carrier with the collector mirror into a cleaning tank;

applying a cleaning agent to a reflective surface of the collector mirror by spraying the cleaning agent through a plurality of nozzles directed toward the collector mirror reflective surface until the collector mirror reflective surface is clean;

rinsing the applied cleaning agent from the collector mirror reflective surface; and

drying the collector mirror reflective surface.

26. The method of claim 25, wherein the collector mirror is an ellipsoidal mirror.

27. The method of claim 25, wherein the collector mirror is positioned within the chamber of the extreme ultraviolet light source so that the amplified light beam passes through an aperture of the collector mirror before reaching the target region.

28. The method of claim 25, wherein mounting the collector mirror to the carrier comprises holding a flat rim of the collector mirror between front and back panels of the carrier.

29. A method for cleaning a collector mirror of an extreme ultraviolet light source, the method comprising:

removing a collector mirror having an ellipsoidal reflective surface from a chamber of the extreme ultraviolet light source;

mounting the collector mirror to a carrier;

inserting the carrier with the collector mirror into a cleaning tank;

applying a cleaning agent to the ellipsoidal reflective surface of the collector mirror by spraying the cleaning agent through a plurality of nozzles directed toward the ellipsoidal reflective surface until the ellipsoidal reflective surface is clean;

rinsing the applied cleaning agent from the ellipsoidal reflective surface; and

drying the ellipsoidal reflective surface of the collector mirror.

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